Fermilab

Beam-Beam Effects in Tevatron: Past, Present and Future

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for Beam-Beam Team

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Introduction

Accelerator Complexity Levels:

- Zero-Beam:
  - magnets, vacuum, optics, alignment, injection, RF, etc

← Very well understood, good models, ready to build

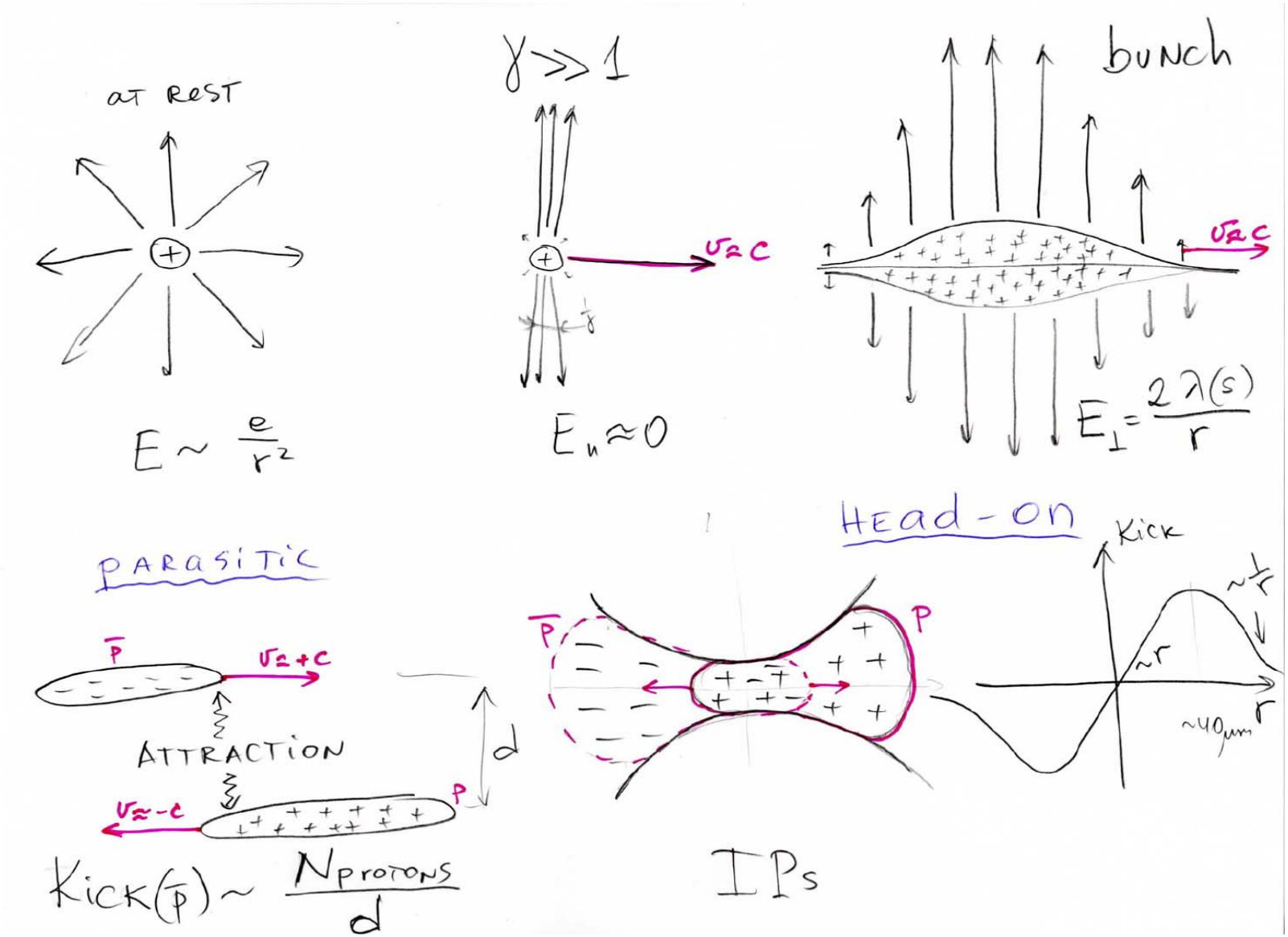
- One-Beam:
  - instabilities, Space Charge, cooling, beam loading

← some understanding, cures known, lots of modeling …still some risk

- Two-Beam:
  - Beam-Beam Effects Electron/Ion Clouds

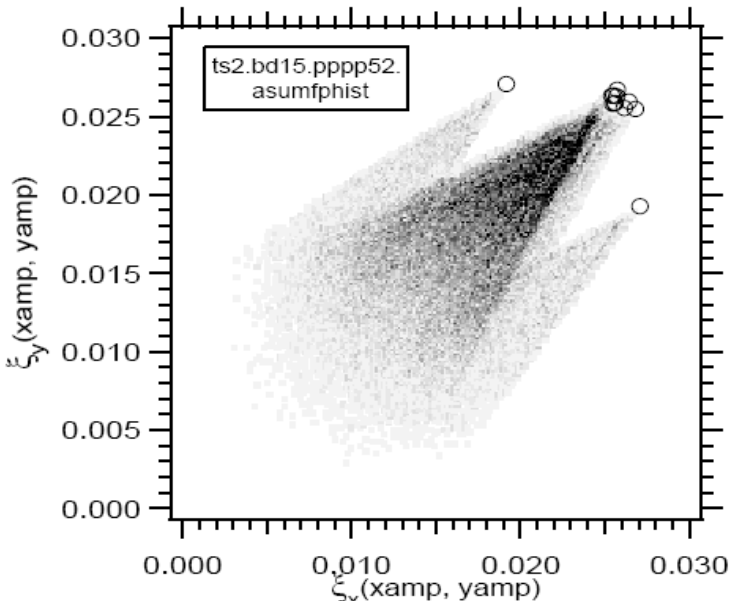
← risky, experiment ahead of theory/modeling (esp. for hadron colliders)

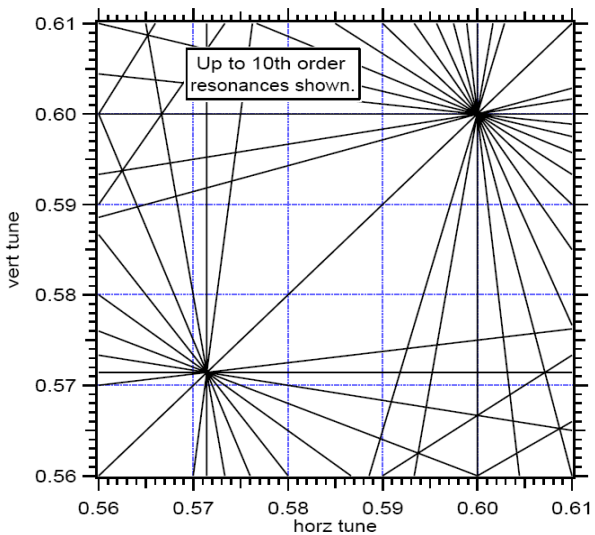
Beam-Beam Effects: Basics



What we knew in 2001

RUN II HANDBOOK





TM-1970 (1995)

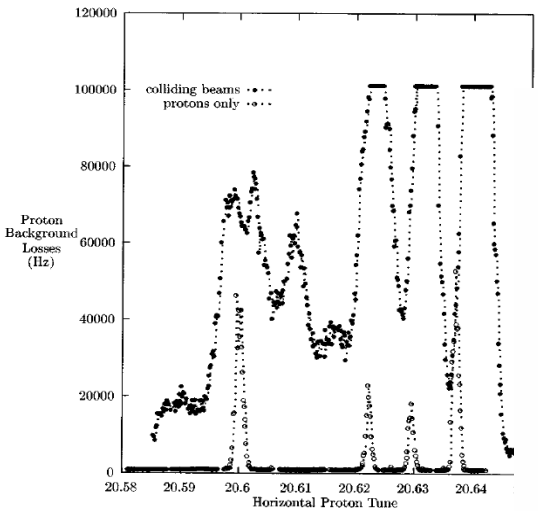
Run Ib a) 6x6 → 2 head-on +10 long-range IPs
b) at 150: -7% p's -3% pbars
c) ramp-LB: -3% p's -10% pbar
d) dN_a ~ Emittance (4…14 pi)
e) shrinkage at 150 – small aperture?
f) nothing particularly bad in collisions

Run II: a) 36x36 → 2 HO +70 LR
b) same head-on tune shifts
c) end-of-train pbar bunches be different in collisions

Overall = "should be tolerable…as in Run I"
… but 36xn studies in 1995 raised concerns

$$\xi = \frac{N_p r_p}{4\pi\varepsilon_p} \approx 0.025$$

D. SIERGIEJ, D. FINLEY, AND W. HERR



Peter Bagley

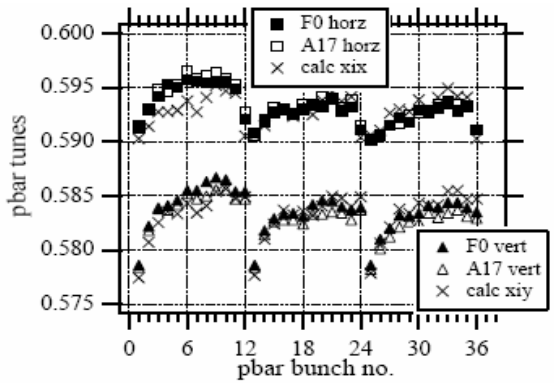
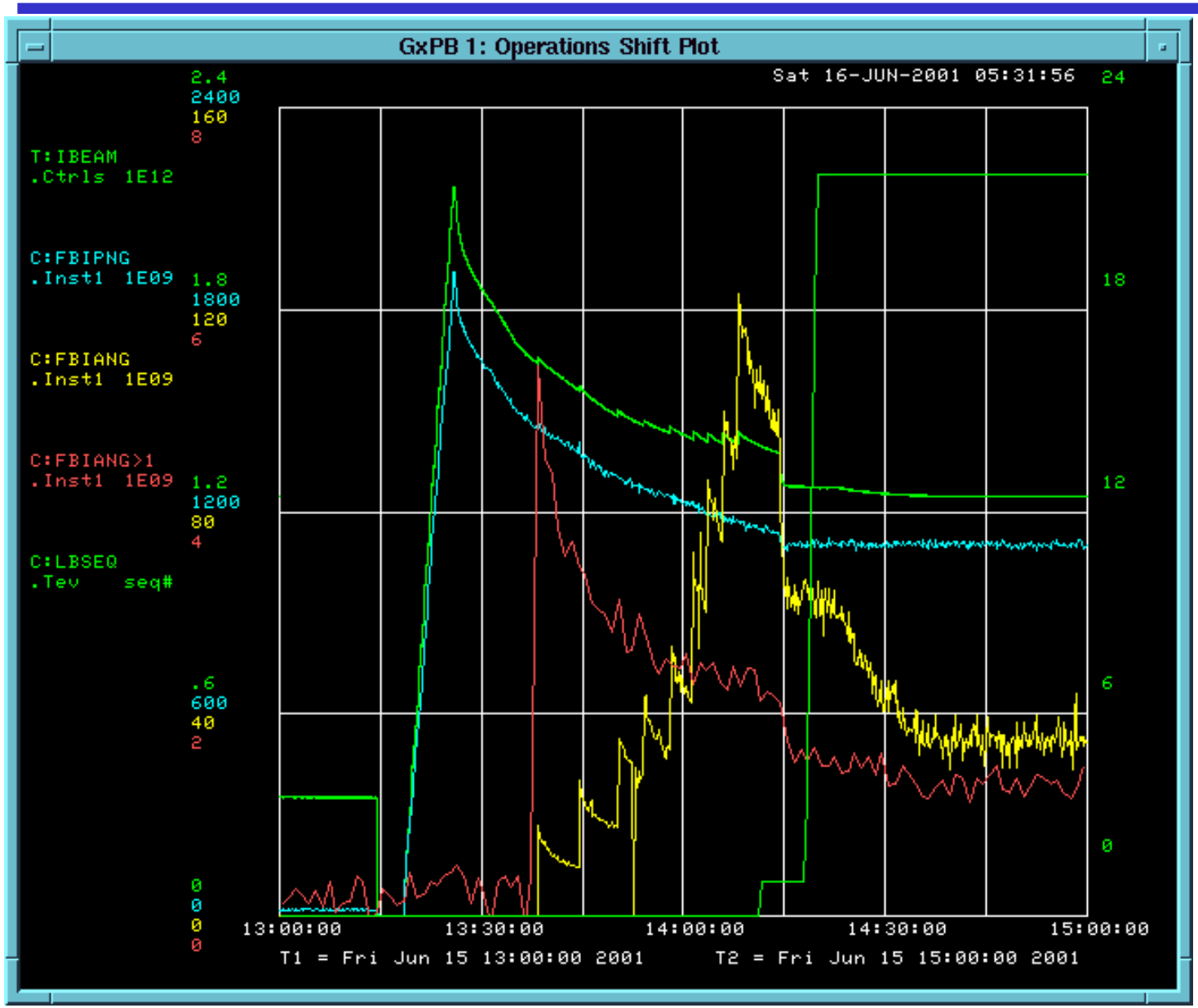


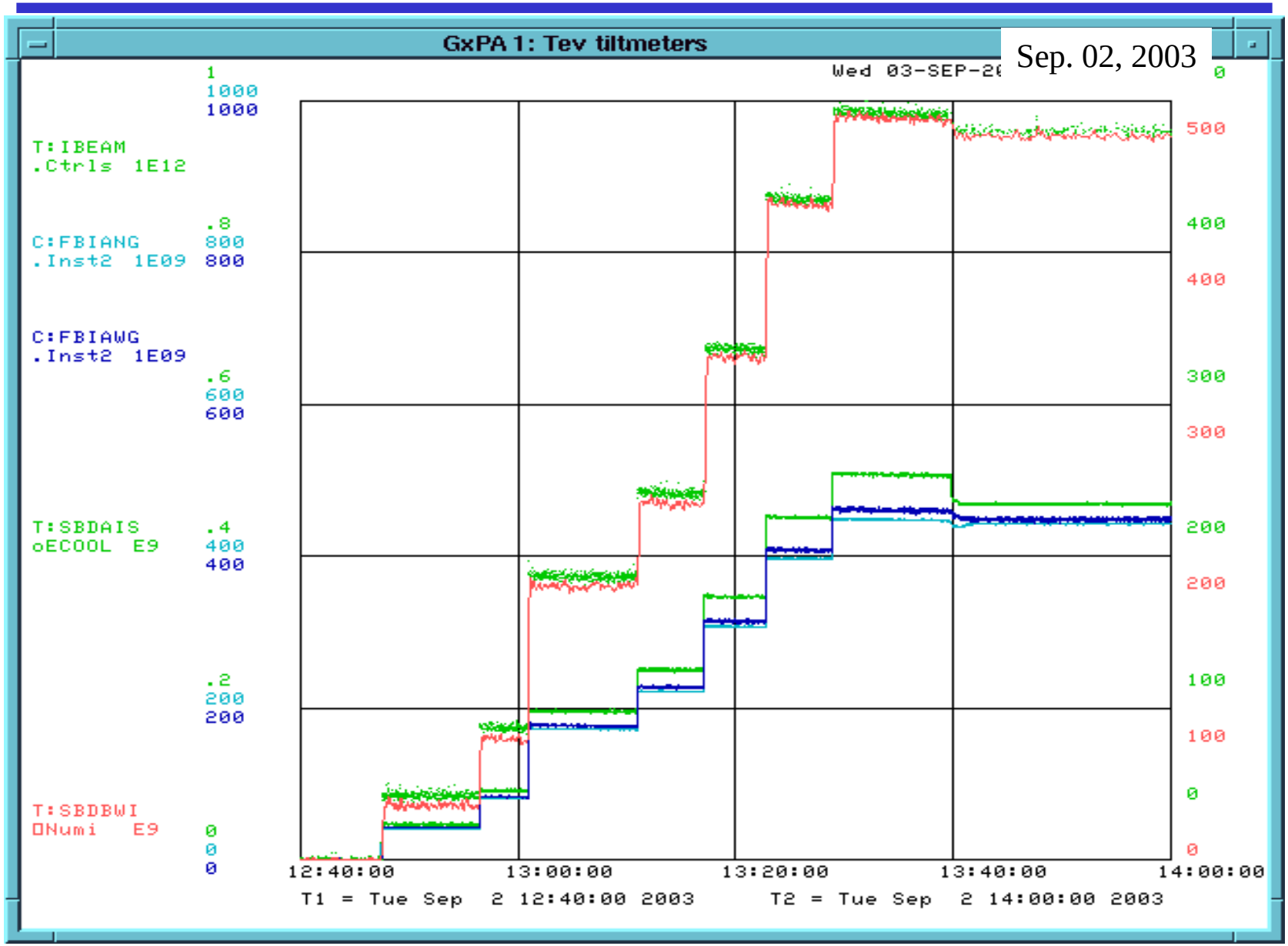
Figure 2 : Measured and Calculated Pbar Tunes for

Tevatron Inefficiencies: 2001

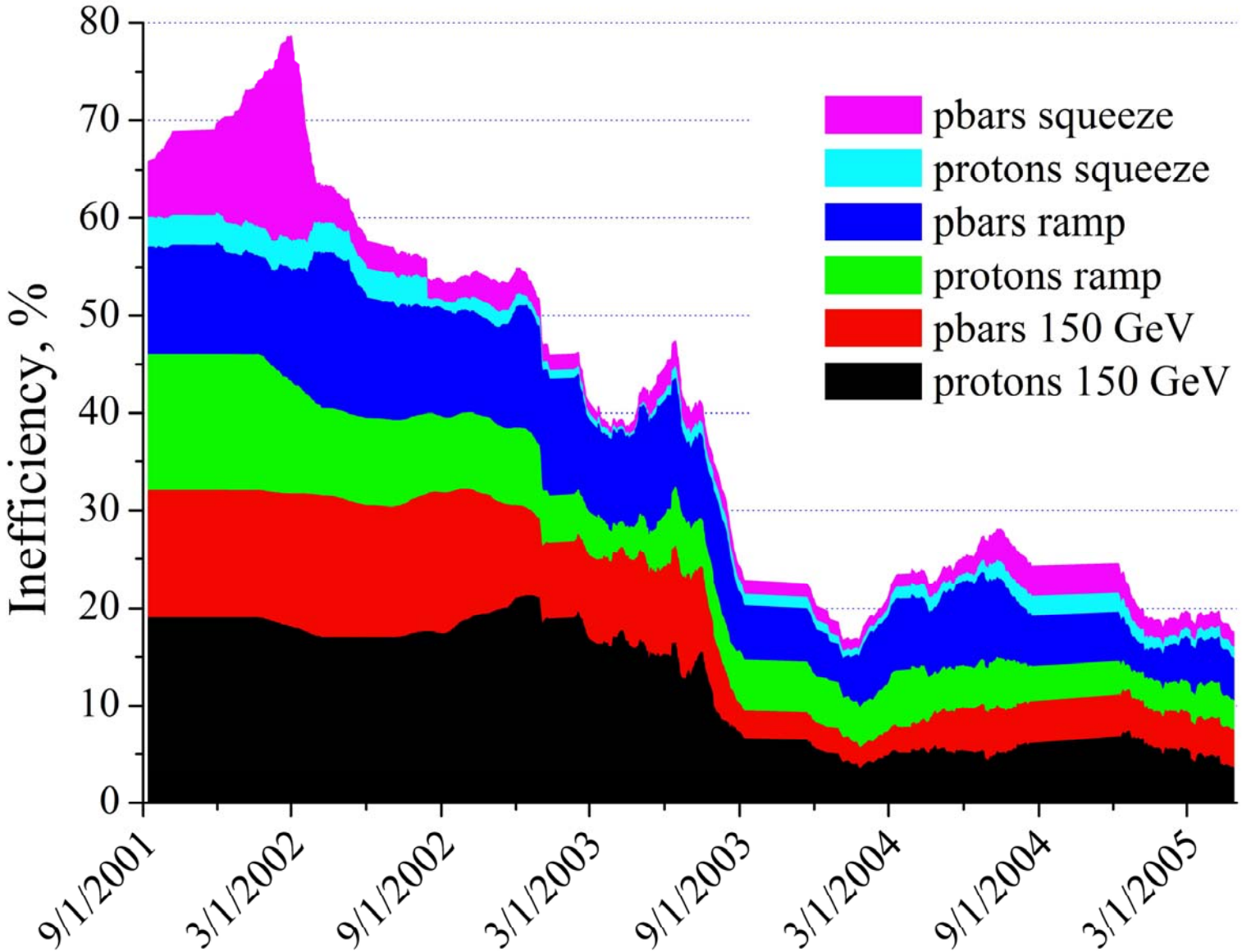


Store #535
Jun 15, 2001

No Other Beam - No Losses! (Pbar Only Store)



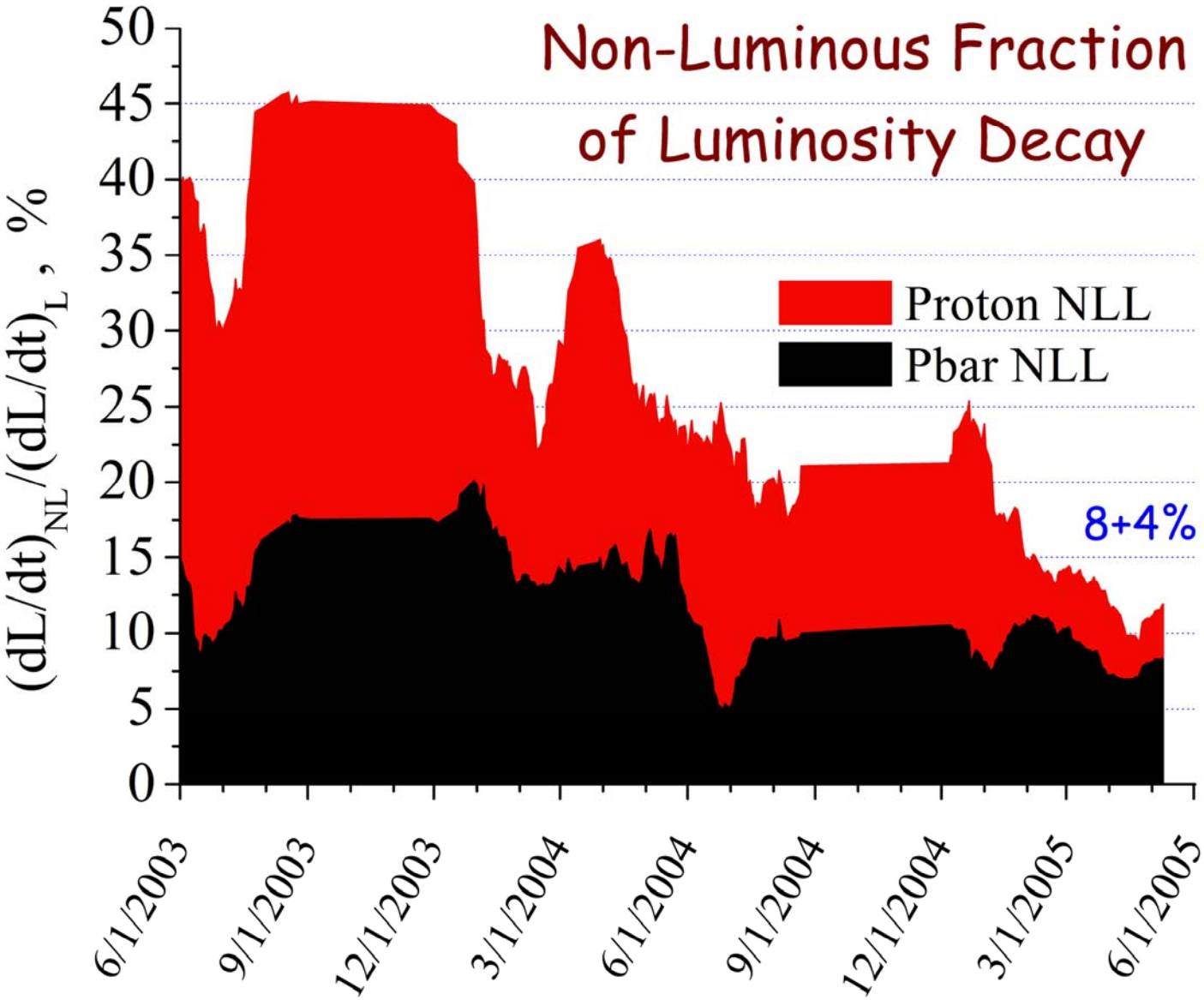
Tevatron Inefficiencies: 2001-2005



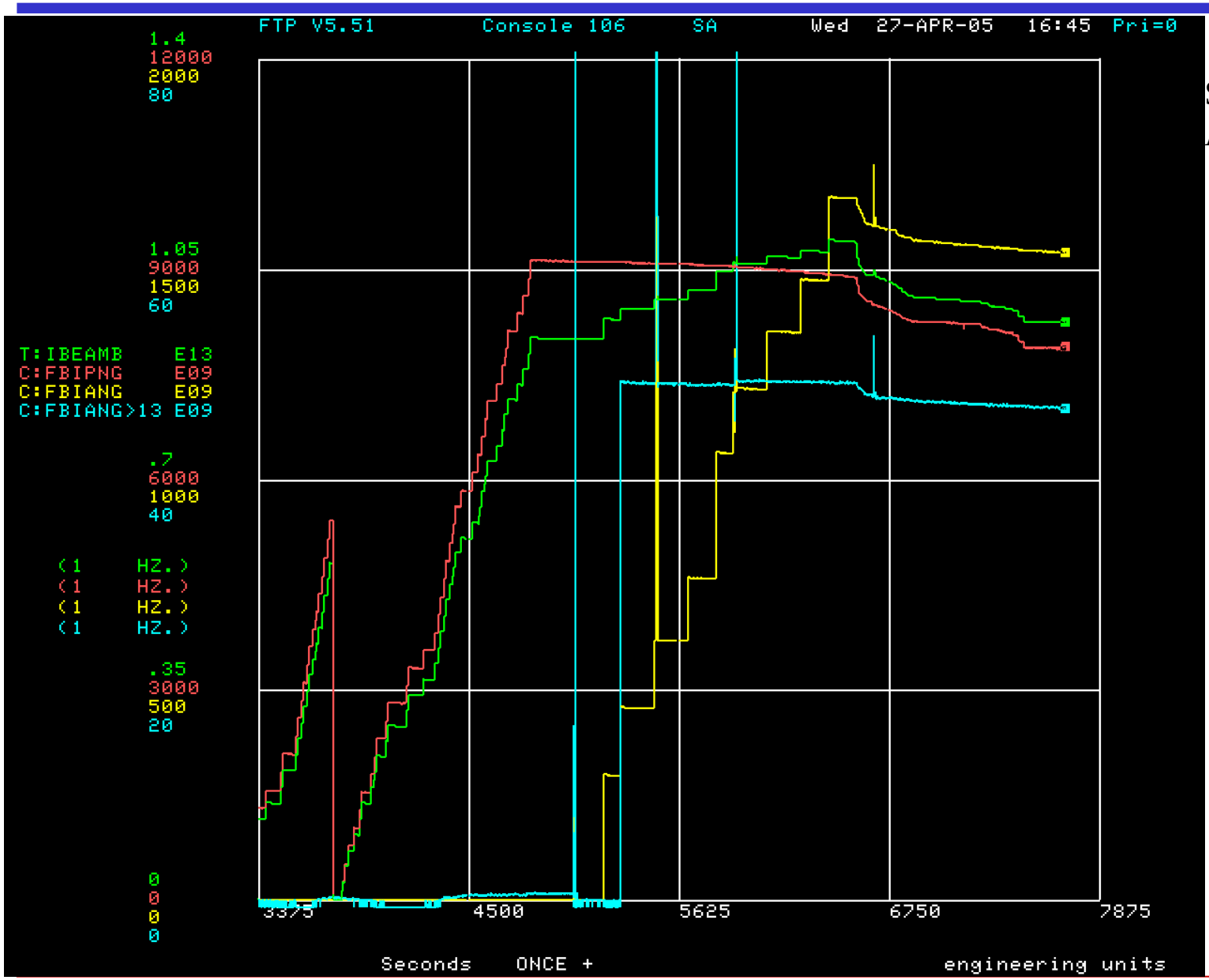
???

Jun 2009

L-Lifetime Affected by Beam-Beam



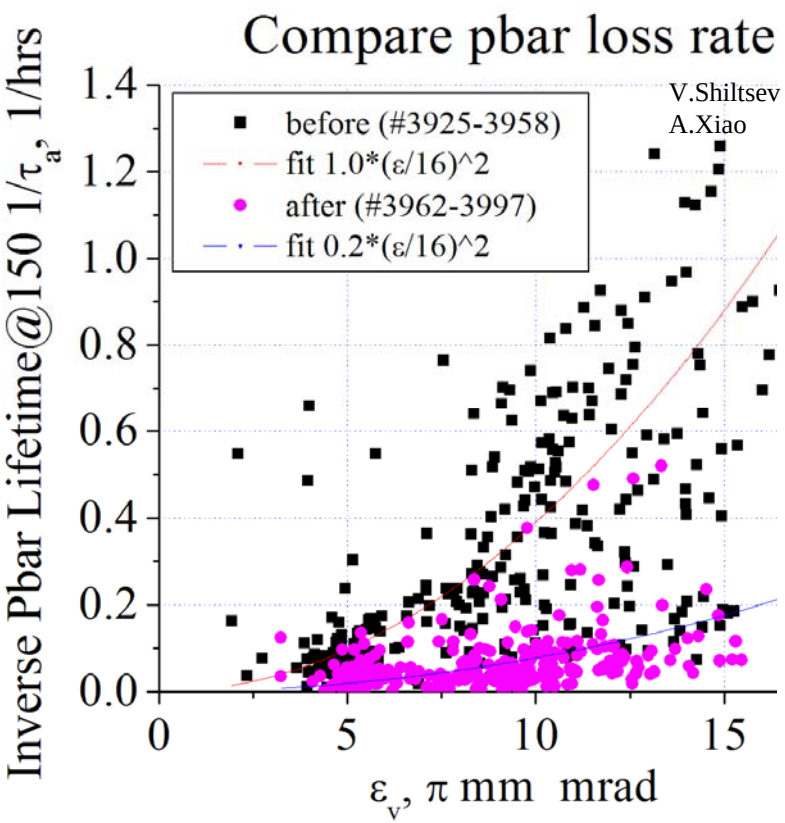
Tevatron Inefficiencies: 2005

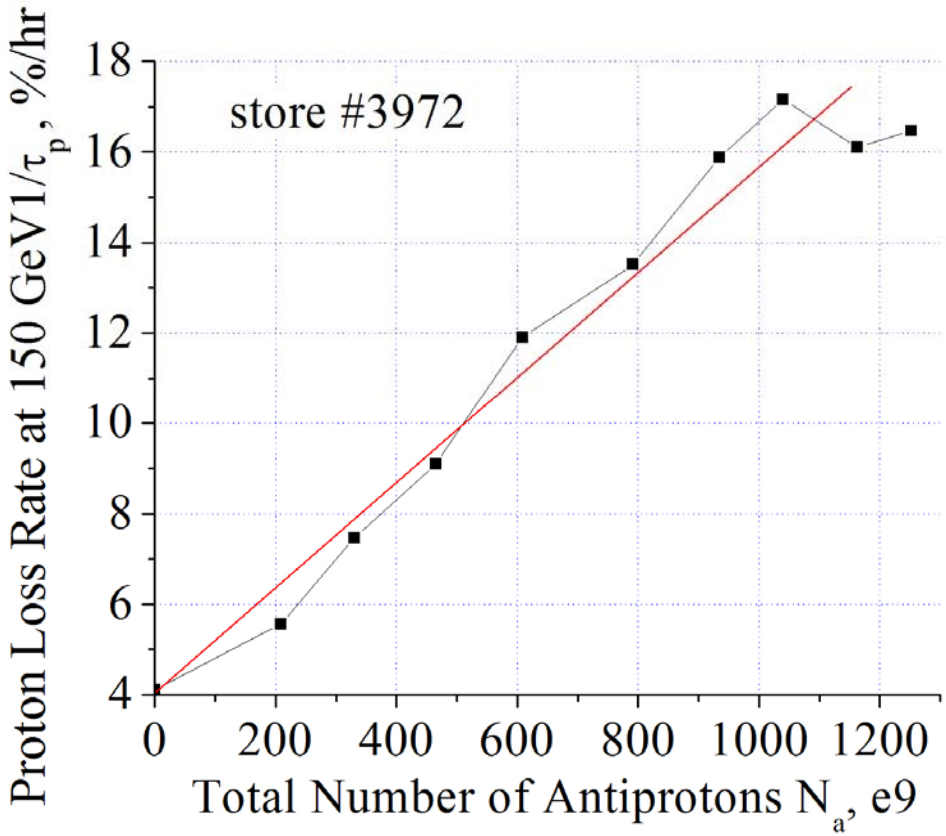


Store #4116
Apr 27, 2005

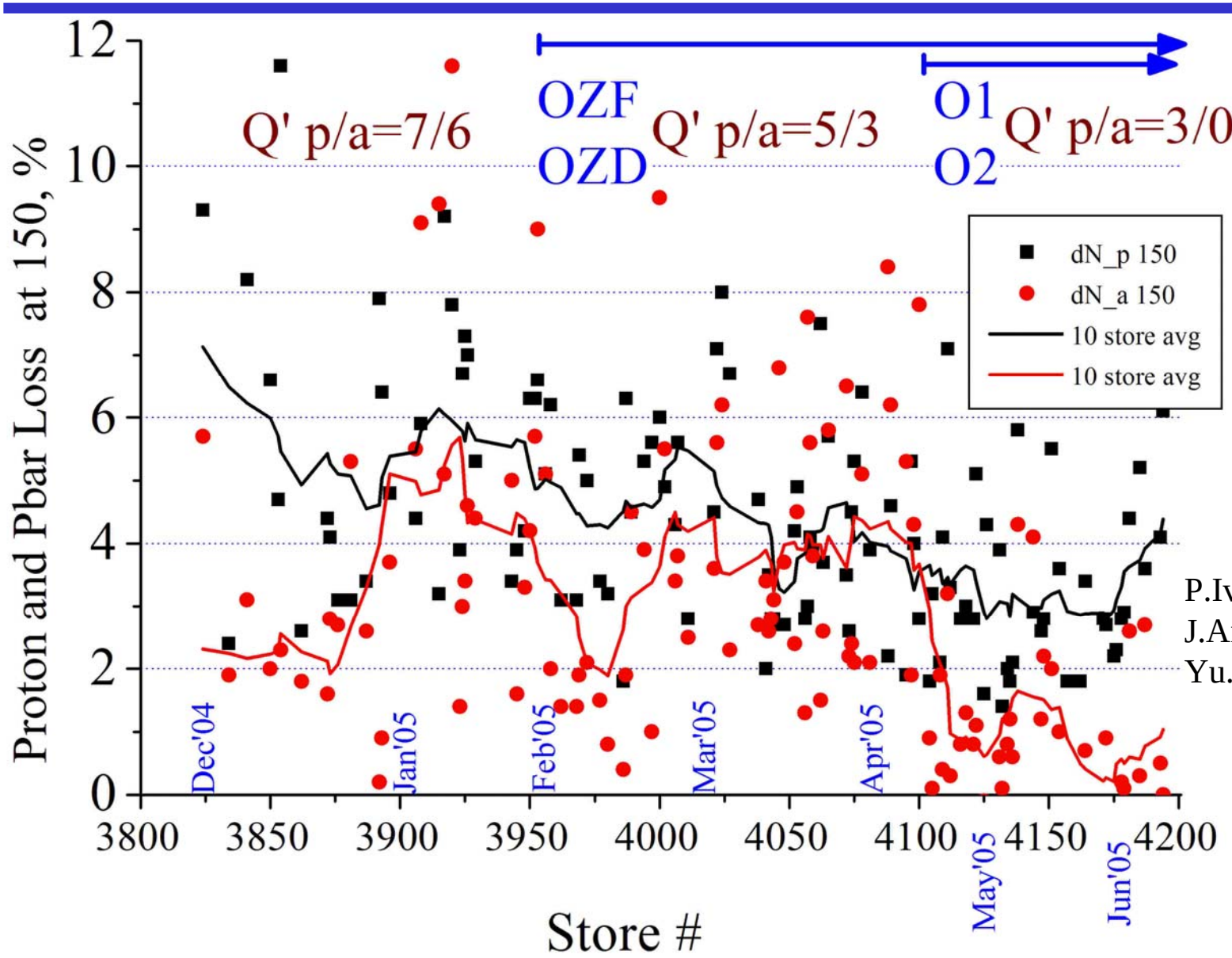
Beam Loss at Injection Helix

$$\frac{dN_{a,p}}{N_{a,p}} \propto \sqrt{t} \cdot \varepsilon_{a,p}^{2} N_{p,a} Q'^{2}{}_{a,p} \times F_1(S_{a-p}, Q_{a,p}, \frac{dP}{P})$$





Octupoles to Drop Chromaticity Q'=dQ/(dp/p)



P.Ivanov
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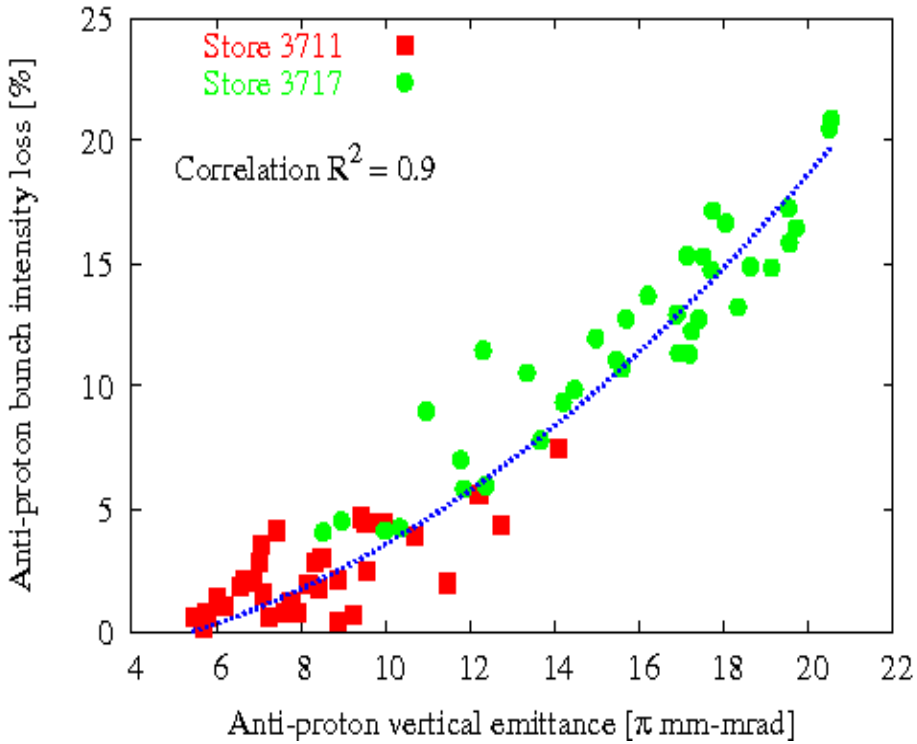
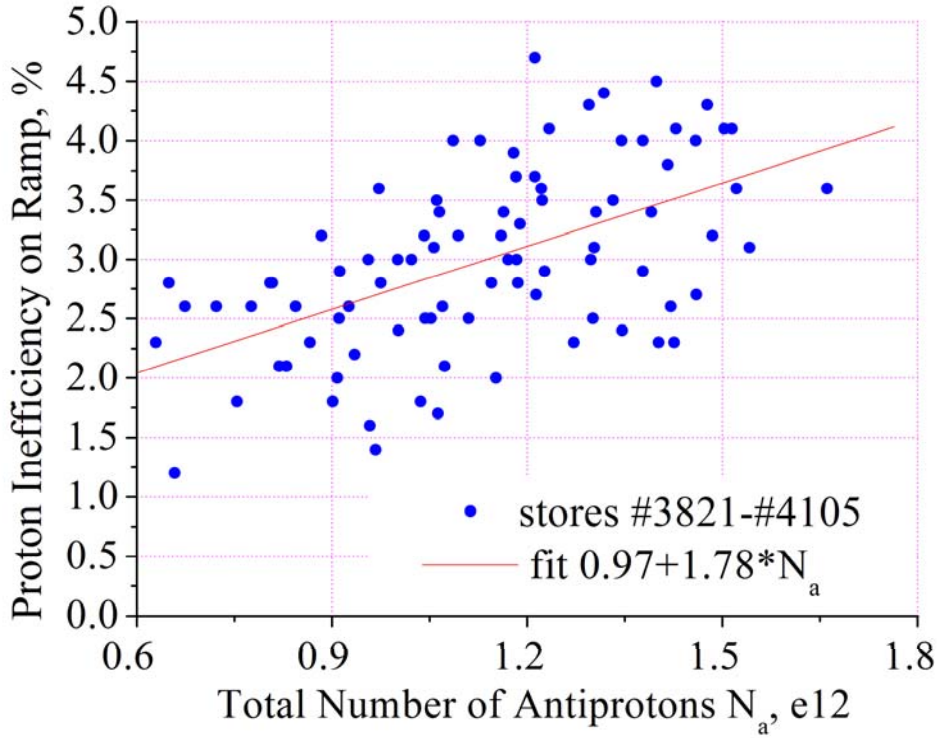
Beam Loss on Ramp

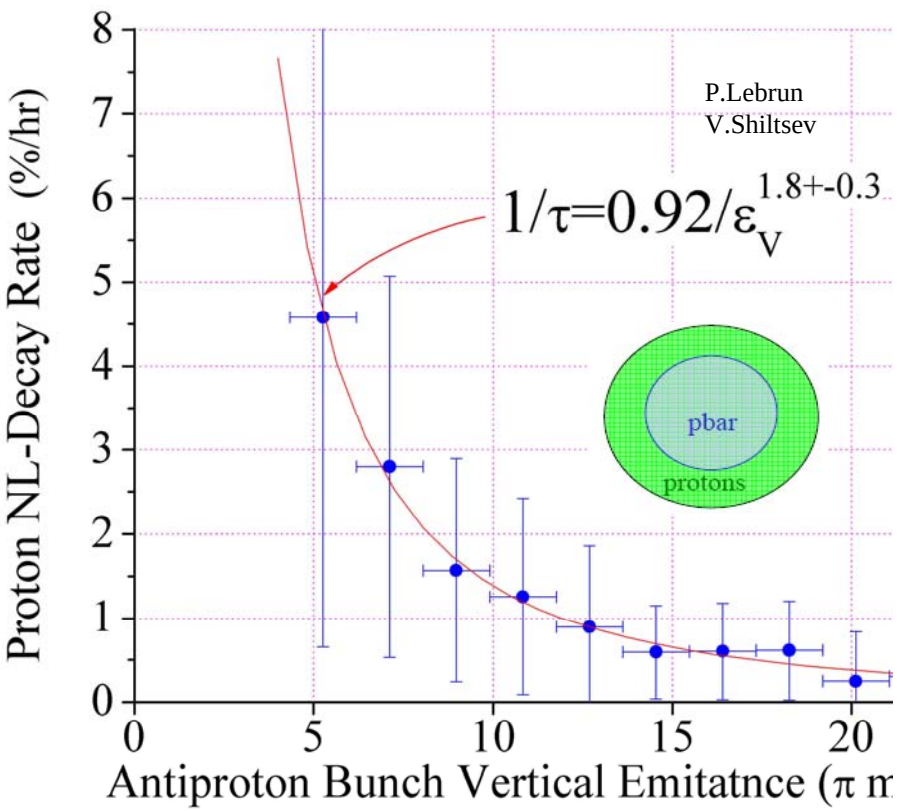
$$\frac{dN_{a,p}}{N_{a,p}} \propto \varepsilon_{a,p}^{2} N_{p,a} \times F_2(S_{a-p}, Q_{a,p}, Q'_{a,p})$$

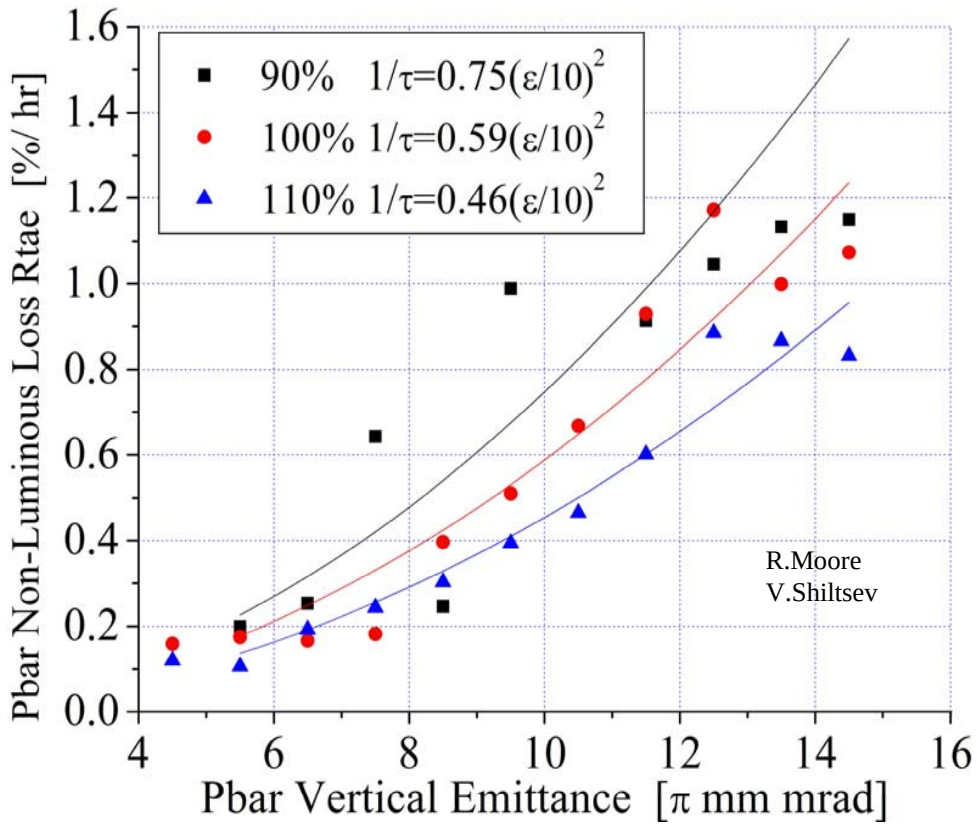




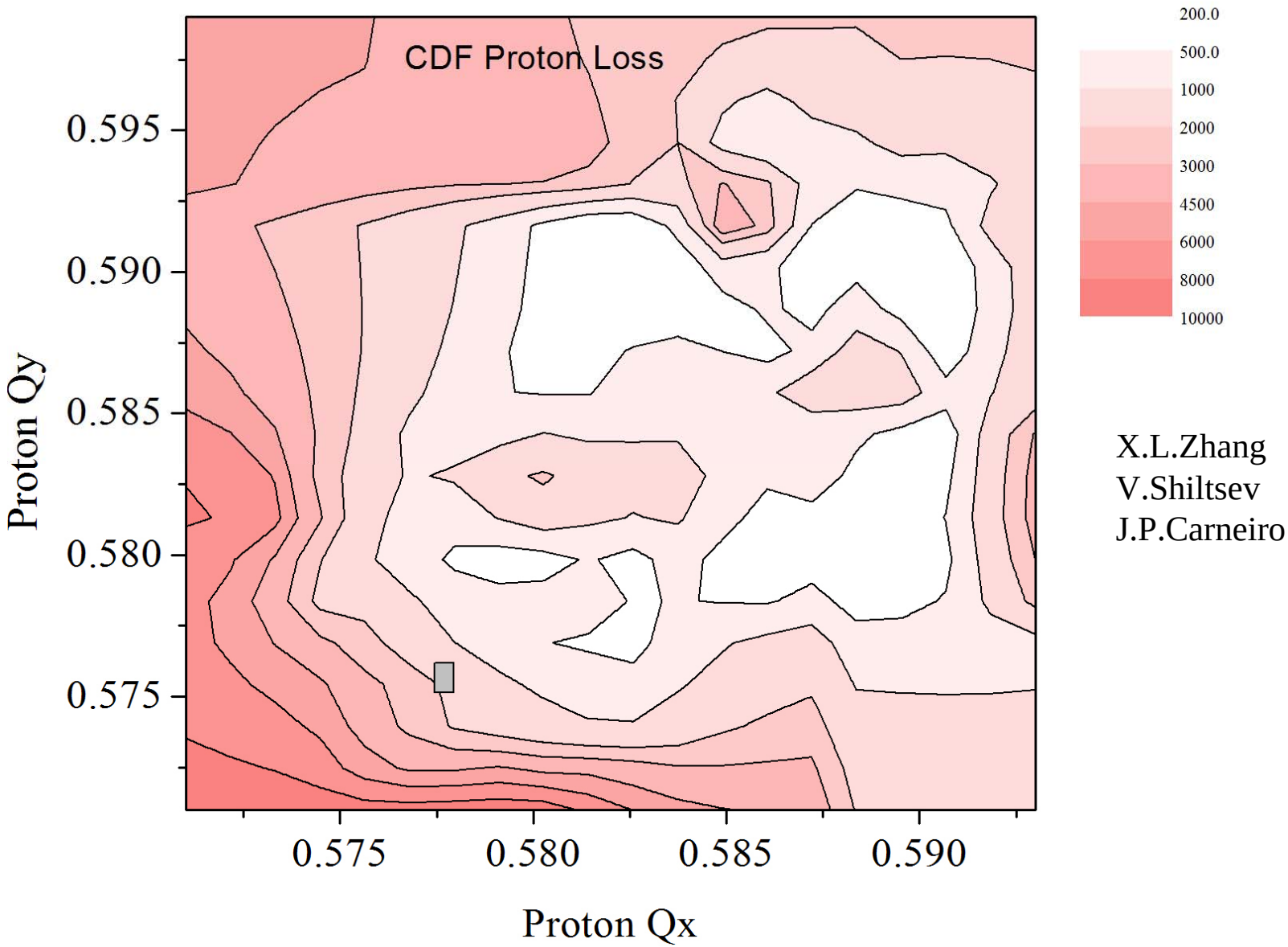
Beam Loss in Collisions

$$\frac{dN_p}{N_p dt} \propto \frac{N_a}{\varepsilon_a^2} \times F_3(Q_p, Q'_p) \qquad \frac{dN_a}{N_a dt} \propto N_p \frac{\varepsilon_a^2}{S_{a-p}^3} \times F_4(Q_a, Q'_a)$$





For Example: Function $F_3\ (Q_{x,y})$



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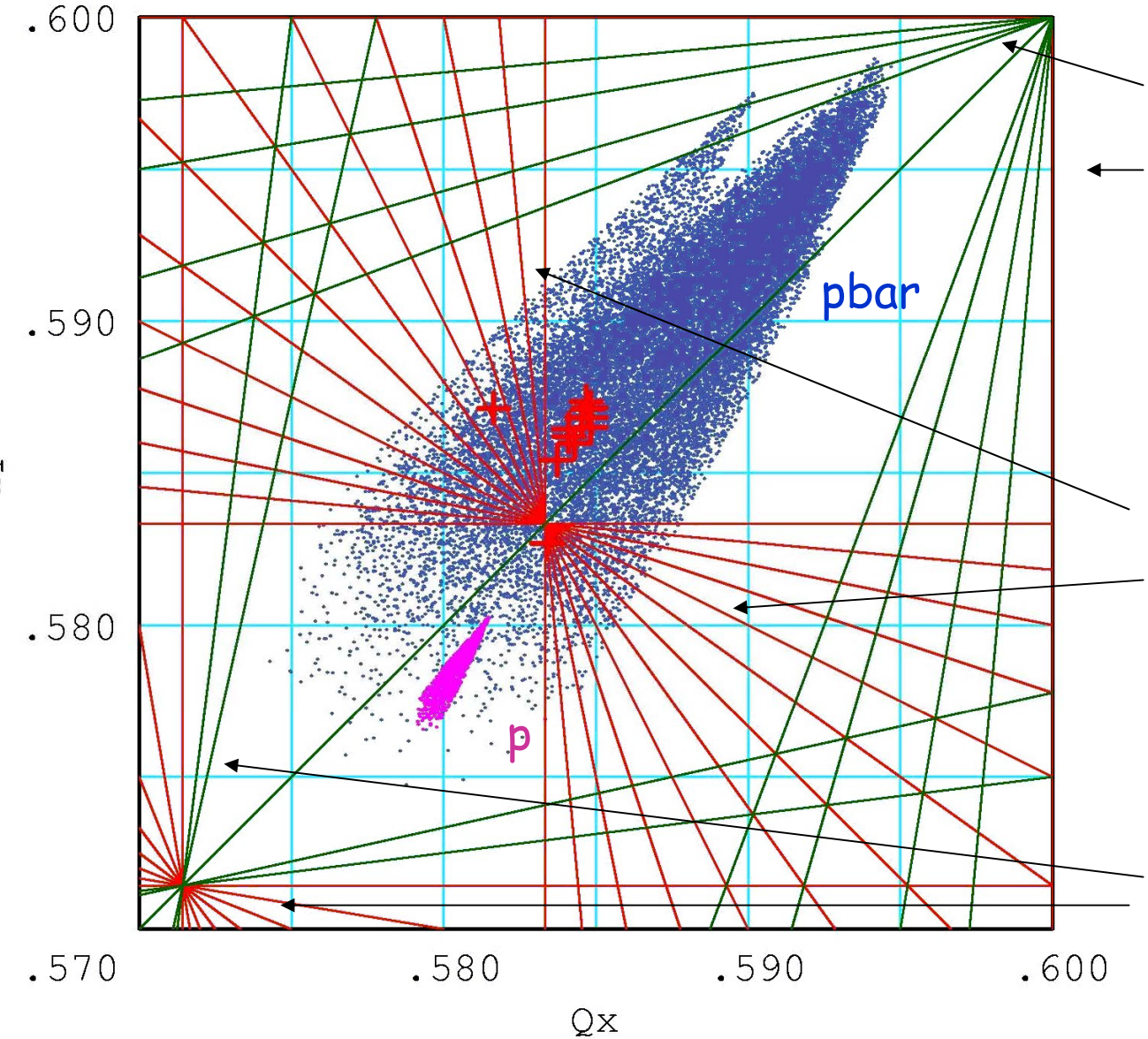
Science and Art of Tevatron Tuning

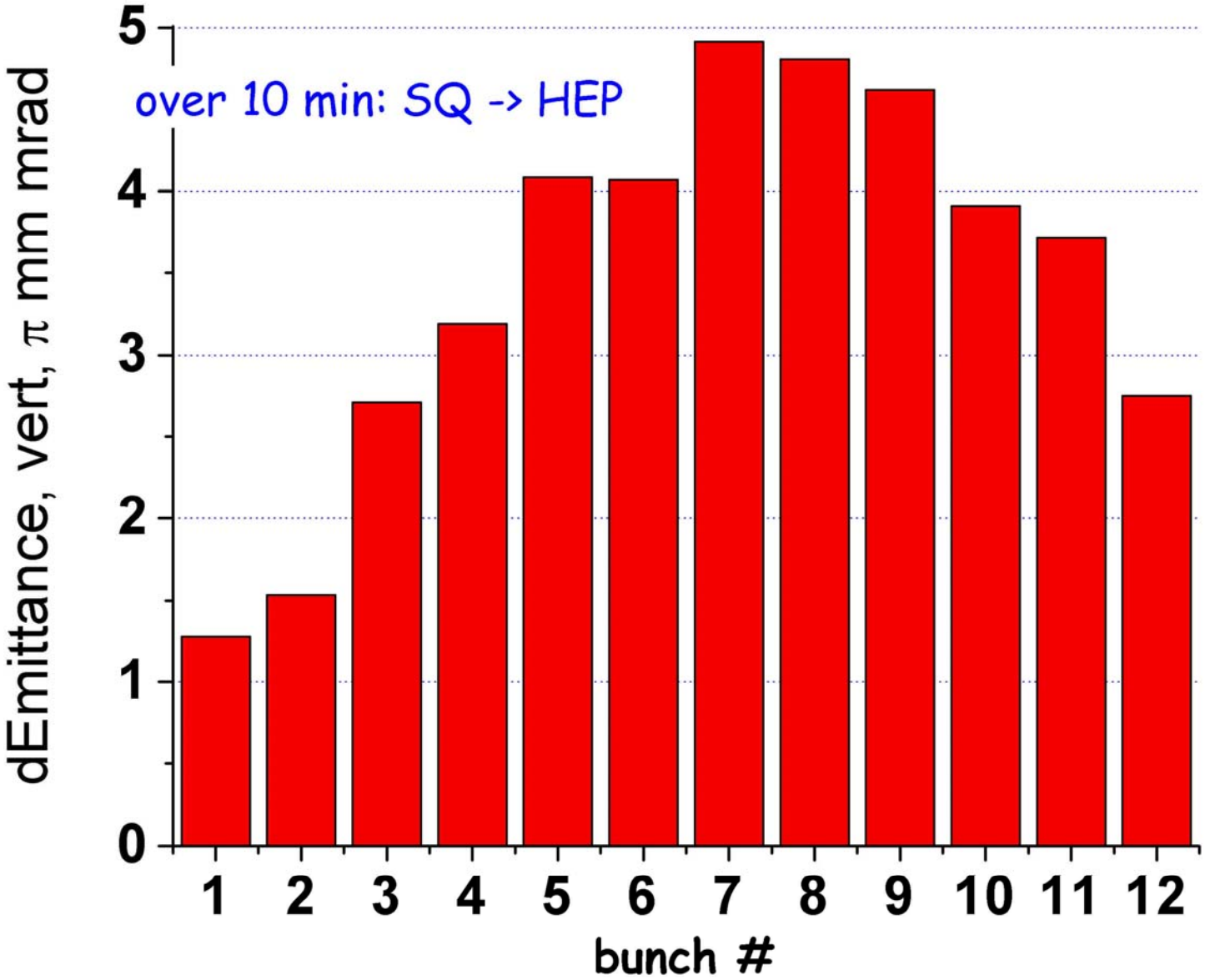


5th order resonances:
Q=3/5=0.600 -
EMITTANCE BLOWUP

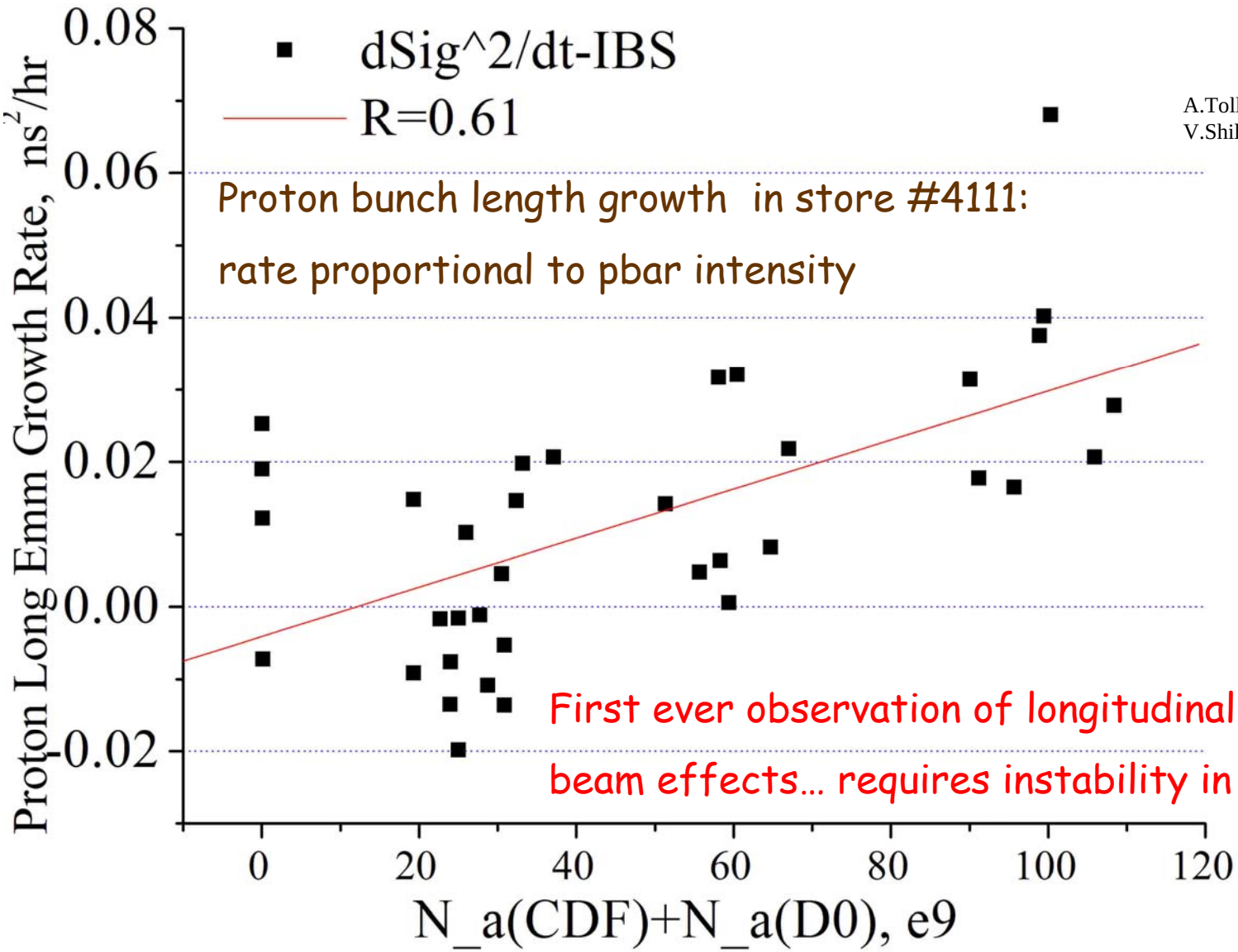
12th order resonances:
Q=7/12=0.583 -
Bad lifetime

7th order resonances:
Q=4/7=0.571 -
HIGH LOSSES

Pbar Bunch Emittance Growth



For Curious: "Alvins' Effect"



Summary on Beam-Beam Effects :

- "Beam-Beam" manifests itself in:
  - beam losses at 150, ramp, squeeze, in store
  - emittance growth in collisions/scraping at 150 GeV
- BB-Losses of protons and pbars are comparable !
- Long range beam-bean effects dominate
- Head-On effects determine only:
  - proton losses in collisions
  - pbar size growth if mistuned
- Most effective counter-measures so far:
  - helix redesigned everywhere (inj, ramp, squeeze, LB)… several times
  - physical apertures opened by Tev alignment
  - beam emittances reduced in injectors and by Tev alignment
  - chromaticity dropped by octupoles in 2005 (dampers in 2003-04)
- Major scaling laws with predictive power revealed
- Theory and simulations are far behind experiment

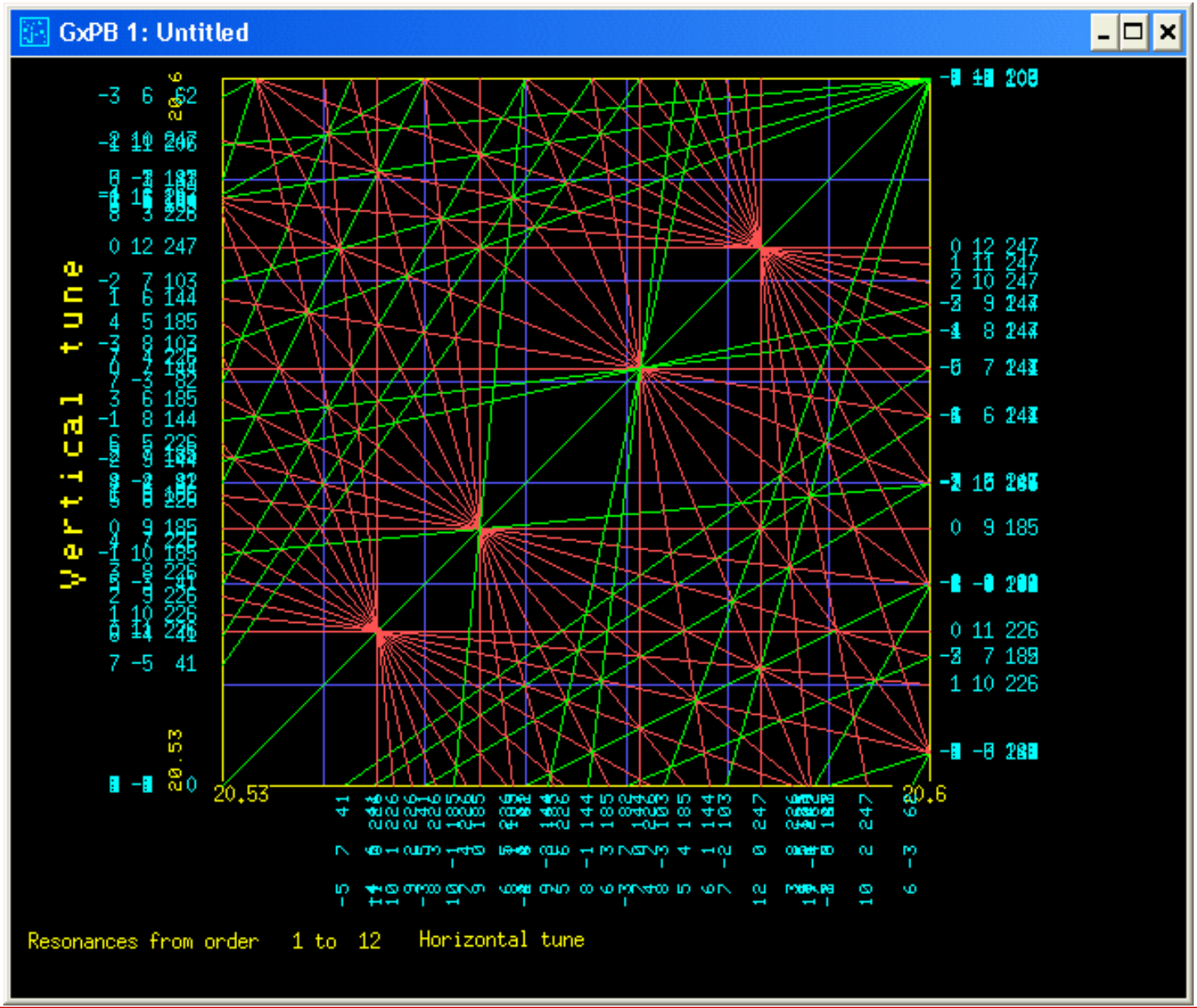
Tev Inefficiencies: Projections for FY09

	Mar-Apr'05	*IF RUN "AS NOW"!*	
	Now	3xN_a	3xN_a 1.4xEmm
P at 150	4.4% ± 2.8	13.2	13.2
A at 150	3.9% ± 2.2	3.9	7.8
P ramp	3.4% ± 0.9	8.2	8.2
A ramp	4.7% ± 1.2	4.7	8.4
P squeeze	1.0% ± 0.4	3.0	3.0
A squeeze	1.5% ± 0.5	1.5	2.0
Total before LB	*18.9% ± 3.9*	*34.5*	*42.6*
Tau_p at LB	160 hr ± 60	~60	~100
Tau_a at LB	160 hr ± 60	~160	~80
Total in Tau_L	*10% ± 5*	*~13%*	*~13%*
Total Int-L	***28% ± 7***	***44%***	***50%***

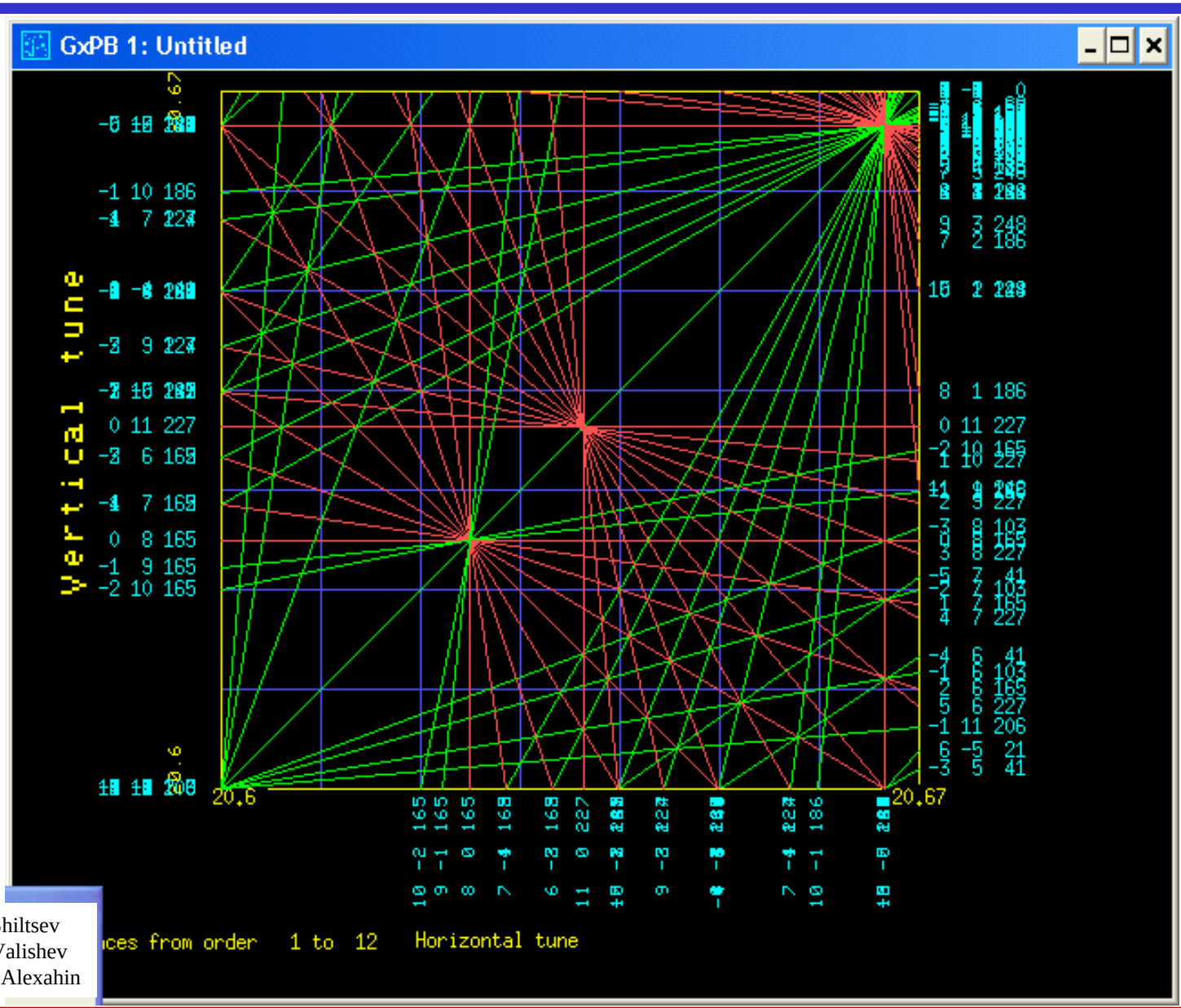
What Will We Work On :

- Better WP for protons at 150, ramp and at LB: 7/12<Q<3/5
- Stabilize pbar tunes in collisions
- Increase helix on ramp and at LB (higher voltage seps, more)
- Drop Q' on ramp and in collisions (octupoles, FB?)
- Reduce beam emittances (inj dampers, MI, RR, AA, Booster)
- Adjust betatron phase advance between two IPs
- Even better working point 3/5 < Q < 7/11
- Change bunch structure, e.g. 46x41 (396 ns spacing) or likes
- Beam-Beam Compensation with TELs

Current Betatron Tune Area



New Betatron Tunes



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